Combat Ocular Trauma Visual Outcomes during Operations Iraqi and Enduring Freedom

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Objective: To report the visual and anatomic outcomes as well as to predict the visual prognosis of combat ocular trauma (COT) during Operations Iraqi and Enduring Freedom.

Design: Retrospective, noncomparative, interventional, consecutive case series.

Participants: Five hundred twenty-three consecutive globe or adnexal combat injuries, or both, sustained by 387 United States soldiers treated at Walter Reed Army Medical Center between March 2003 and October 2006.

Methods: Two hundred one ocular trauma variables were collected on each injured soldier. Best-corrected visual acuity (BCVA) was categorized using the ocular trauma score (OTS) grading system and was analyzed by comparing initial and 6-month postinjury BCVA.

Main Outcome Measures: Best-corrected visual acuity, OTS, and globe, oculoplastic, neuro-ophthalmic, and associated nonocular injuries.

Results: The median age was 25±7 years (range, 18–57 years), with the median baseline OTS of 70±25 (range, 12–100). The types of COT included closed-globe (n = 234; zone 1+2, n = 103; zone 3, n = 131), open-globe (n = 198; intraocular foreign body, n = 86; perforating, n = 61; penetrating, n = 32; and rupture, n = 19), oculoplastic (n = 324), and neuro-ophthalmic (n = 135) injuries. Globe trauma was present in 432 eyes, with 253 eyes used for visual acuity analysis. Comparing initial versus 6-month BCVA, 42% of eyes achieved a BCVA of 20/40 or better, whereas 32% of eyes had a BCVA of no light perception. Closed-globe injuries accounted for 65% of BCVA of 20/40 or better, whereas 75% of open-globe injuries had a BCVA of 20/200 or worse. The ocular injuries with the worst visual outcomes included choroidal hemorrhage, globe perforation or rupture, retinal detachment, submacular hemorrhage, and traumatic optic neuropathy. Additionally, COT that combined globe injury with oculoplastic or neuro-ophthalmologic injury resulted in the highest risk of final BCVA worse than 20/200 (odds ratio, 11.8; 95% confidence interval, 4.0–34.7; $P<0.0005$). Nonocular injuries occurred in 85% of cases and included traumatic brain injury (66%) and facial injury (58%). Extremity injuries were 44% (170 of 387 soldiers). Amputation is a subset of extremity injury with 12% (46 of 387) having sustained a severe extremity injury causing amputation.

Conclusions: Combat ocular trauma has high rates of nonocular injuries with better visual outcomes in closed-globe compared with open-globe trauma. The OTS is a valid classification scheme for COT and correlates the severity of injury with the final visual acuity and prognosis. Globe combined with oculoplastic or neuro-ophthalmologic injuries have the worst visual prognosis.

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The incidence of eye injuries during United States armed conflicts has ranged from 0.5% during the United States Civil War to 13% during Operation Desert Storm (Table 1).[1–14] Although improvements in body armor have allowed soldiers to survive explosions that would have resulted in fatal chest or abdominal wounds in the past, there has been an increasing incidence of injuries to the relatively unprotected extremities, face, neck, and eyes.

From October 2001 through September 2006, the total number of American casualties in Operations Iraqi and Enduring Freedom (OIF/OEF) included 21 695 wounded in action and 2335 killed in action.[15,16] From 2002 through 2007, the number of U.S. military OIF/OEF soldiers with significant battle ocular injuries requiring evacuation was 13%.[13,17,18] However, analysis of visual outcomes of all combat ocular trauma (COT) patients during OIF/OEF has not yet been published. This study was designed to report the visual and anatomic outcomes of COT seen at Walter Reed Army Medical Center (WRAMC) and to predict the visual prognosis after the initial injury.

Patients and Methods

The study was conducted under an institutional review/ethics board-approved protocol. It also was approved for publication by the WRAMC's Department of Clinical Investigation and Opera-

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Table 1. United States of America War Casualties

War/Conflict	Killed in Action[1]	Wounded in Action[1]	Combat Ocular Injuries*	Total Published Cases of Combat Ocular Trauma
Revolutionary War (1775–1783)	4435	6188	N/A	N/A
War of 1812 (1812–1815)	2260	4505	N/A	N/A
Mexican War (1846–1848)	1733	4152	N/A	N/A
Civil War (Union forces only; 1861–1865)	140 414	281 881	0.57%[2]	1190[8]
Spanish-American War	385	1662	2.2%[8]	35[8]
World War I (1917–1918)	53 402	204 002	2.1%–2.4%[4,7,8]	3157[8]
World War II (1941–1946)	291 557	671 846	2.0%–2.2%[3,7,14]	11 970[8]
Korean War (1950–1953)	33 741	103 284	2.8%–8.1%[8,9]	2032[9]
Vietnam conflict (1964–1973)	47 424	163 303	9%[36]	4585[36]
Persian Gulf War (1990–1991)	147	467	13%[11]	19[11]
Operations Iraqi and Enduring Freedom†	3432	30 484	13%[13,17]	1086‡[13,17]

N/A = not available.
*Published rates of combat ocular trauma.
†October 2001 through December 2007.
‡March 2003 through June 2006.

tional Security. This retrospective, noncomparative, interventional case series examined all United States soldiers injured during OIF/OEF who were evacuated from the theater of operations through Germany to WRAMC, Washington, District of Columbia, from March 2003 through October 2006.[19] All patients in this study were examined and followed up at WRAMC until the soldier's return to duty or to the time of discharge into the Veteran's Affairs medical system. Patients were identified from a Global War on Terrorism database developed and maintained by the WRAMC Ophthalmology Service since the onset of Operation Iraqi Freedom in 2003. Included in this database are all patients seen at the Ophthalmology Service for diseases, non-battle injuries, and battle injuries sustained in the combat theater of operations. Inpatient records, outpatient records, transfer summaries, operative reports, and all other available existing data on each patient were collated into a study file. Information then was recorded onto a standardized data collection sheet that was used for data entry into a structured database program for analysis (SPSS software version 15.0; SPSS, Inc., Chicago IL). Data collection included variables from the time of injury to the end of follow-up. Two hundred one ocular trauma variables were collected on all patients for a total of 105 123 data points. Main outcome measures were collected for all injuries (Fig 1). Inclusion criteria were American soldiers injured during combat operations in the theater of Iraq or Afghanistan. Exclusion criteria were American nonbattle injuries or injuries sustained outside a combat zone and ocular trauma in Iraqi or Afghan civilians, allied forces, and enemy combatants.

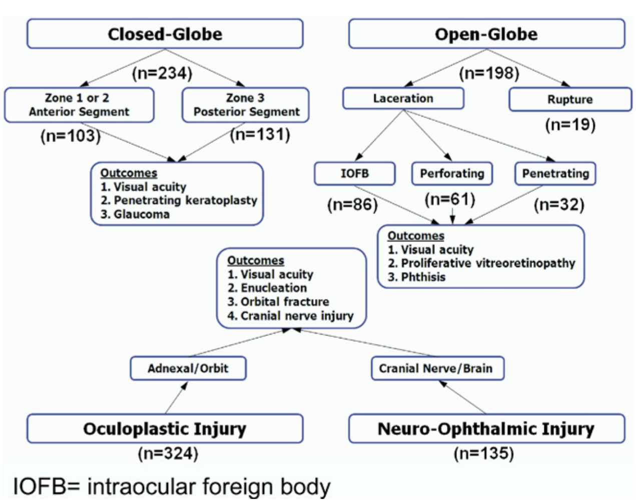

Figure 1. Flowchart showing the classification and outcome measures of combat ocular trauma. IOFB = intraocular foreign body.

Injuries were classified as closed or open globe in accordance with the Birmingham Eye Trauma Terminology (BETT).[20–22] Injuries not involving the globe were categorized as oculoplastic or neuro-ophthalmologic injuries (Fig 1). The ocular trauma score (OTS) was calculated retrospectively as described by Kuhn et al.[23] The OTS provides a single probability estimate that an eye trauma patient will obtain a specific visual range by 6 months after injury. The OTS uses initial visual acuity and injury type to predict an outcome based on findings at the time of presentation. Table 2 describes calculation of the OTS. Higher OTS indicates a better prognosis. The OTS then can be used to predict the final visual acuity.[23] The OTS can be used as an aid in patient counseling of eye injury patients and can assist in identifying severe ocular injuries with a poor visual prognosis.[23,24]

The initial and final visual acuities were converted from Snellen acuity to OTS grade for statistical analysis. Snellen visual acuities could not be converted into logarithm of the minimum angle of resolution units because of the large percentage of eyes with best-corrected visual acuity (BCVA) worse than 20/200. Grade 1 was no light perception. Grade 2 was hand motions or light perception. Grade 3 BCVA was 20/200 to 1/200 (counting fingers). Grade 4 BCVA was 20/50 to 19/200. Grade 5 BCVA was 20/15 to 20/40. The postinjury visual acuity was analyzed sepa-

Table 2. Ocular Trauma Score Calculation

Initial Vision	No. of Points	Subtract for Each Diagnosis	No. of Points
NLP	60	Rupture	−23
LP/HM	70	Endophthalmitis	−17
1/200–19/200	80	Perforating injury	−14
20/200–20/50	90	Retinal detachment	−11
≥20/40	100	APD	−10

APD = afferent pupillary defect; HM = hand movements; LP = light perception; NLP = no light perception.

rately in this study at the 30-day, 180-day, and the last documented visual acuity date. Seventy-seven eyes with only oculoplastic injuries and 18 eyes with only neuro-ophthalmic injuries were excluded from visual outcome analysis. Of the 432 globe injuries, 167 eyes did not have a documented visual acuity at 180 days after injury and 12 eyes were missing initial visual acuity. Therefore, the visual acuity outcome analysis included only globe injuries with documented initial and 180-day visual acuities ($n = 253$). Twelve patients encompassing 17 ocular injuries could not communicate visual acuity secondary to severe traumatic brain injury (TBI). Initial and final visual grades were analyzed using both the 2-tailed paired-samples *t* test and Wilcoxon signed-rank test. Results of visual acuity grades are reported as mean±standard error.

This study retrospectively explored the prognostic factors that may predict good and poor visual outcomes using the OTS.[23] Ocular trauma score calculations were performed on the 253 eyes with globe injury comparing initial versus 180-day visual acuities. Eyes then were categorized by OTS as follows: category 1 (0–44), category 2 (45–65), category 3 (66–80), category 4 (81–91), and category 5 (91–100). Statistical analysis was calculated using a bivariate 2-tailed significant Spearman correlation coefficient.

Univariate and multivariate statistical analysis was performed on globe injuries ($n = 432$) using 86 832 data points to determine what factors predispose to good visual outcome (OTS grades 4 and 5) versus poor visual outcome (OTS grades 1–3). Univariate analysis was calculated using chi-square 2-sided significant testing. Risk estimates were computed using odds ratios (ORs) with 95% confidence intervals (CIs).

The dependent variable in the multiple logistic regression analysis was BCVA of 20/200 or better compared with BCVA worse than 20/200. The covariates were globe plus oculoplastic or neuro-ophthalmologic injury, oculoplastic plus globe or neuro-ophthalmologic injury, neuro-ophthalmologic plus globe or oculoplastic injury, globe injury only, oculoplastic injury only, and neuro-ophthalmologic injury only. A forward and backward conditional method was used to formulate the ORs and 95% CIs.

Vitreous hemorrhage was graded from 1 through 4 by retrospective analysis of medical records. Vitreous hemorrhage grade 1 was retinal detail visible from the posterior pole to the ora serrata, grade 2 was large vessels visible, grade 3 was the presence of a red reflex with no central retinal detail, and grade 4 was no red reflex.

The timing of initial visual acuity measurement was highly variable because of the circumstances in which the injuries occurred. In general, visual acuity is recorded as early in the course of care as possible in every case. Injured soldiers were evacuated rapidly to a combat support hospital, where the initial eye evaluation and primary surgical repair are performed by an experienced ophthalmologist, often within hours of the injury. After patients were stabilized at the combat support hospital, they were evacuated through Germany, then on to the United States, often within 72 to 96 hours of injury. Not infrequently, patients experienced devastating nonocular injuries, including orthopedic and neurosurgical emergencies, with resulting delay in ocular evaluation and intervention. As a rule, vision could be assessed adequately only after the soldier regained consciousness, after extubation, or both. For some soldiers, this was within hours of injury in the combat support hospital, whereas for others it was in Germany during the air evacuation process. For still others, the initial documentation of visual acuity was delayed significantly and may have occurred after surgical intervention to explore or repair an open-globe.

In general, injured U.S. Army soldiers were evacuated from Germany to WRAMC, whereas most marines were evacuated to the National Naval Medical Center in Bethesda, Maryland.[25] Notable exceptions included burn victims who were evacuated preferentially to the burn center at Brooke Army Medical Center in San Antonio, Texas. Although occasionally others were evacuated to other facilities on a case-by-case basis, this was the exception to the general evacuation pattern, and the authors estimate that more than 50% of injured soldiers passed through WRAMC.

Soldiers arrived at WRAMC from Germany and were evaluated either in the clinic or in the surgical intensive care unit. Visual acuity in immobile soldiers was obtained at the bedside using a Rosenbaum pocket screener at 14 inches. Visual acuity measurements were recorded when the soldier was able to communicate accurately the visual acuity. For this analysis, intubated and noncommunicative soldiers did not have recorded initial acuities until they were extubated. For ambulatory patients, examination was performed in the eye clinic with standard Snellen visual acuity charts. The Snellen BCVA was obtained at every visit during care in the WRAMC Ophthalmology Clinic.[26]

This study also included all adnexal injuries either isolated or involving the globe. When both globe and adnexal injury occurred on the same side in the same person, it was counted as 1 injury for this study. Bilateral injuries were categorized as globe/globe, globe/oculoplastic, globe/neuro-ophthalmic, oculoplastic/oculoplastic, oculoplastic/neuro-ophthalmic, and neuro-ophthalmic/neuro-ophthalmic. Oculoplastic injuries included eyelid laceration or avulsion, orbital fractures, orbital foreign bodies, retrobulbar hemorrhage, and lacrimal system injury. Neuro-ophthalmic injuries were defined as IIIrd, IVth, or VIth cranial nerve injury from either central or peripheral injury as well as VIIth cranial nerve injury causing eyelid movement disorders. Objective visual field defects from brain injury were categorized as neuro-ophthalmic injury.

Results

From March 2003 through October 2006, 387 U.S. soldiers with 523 globe or adnexal combat injuries, or both, were evacuated to WRAMC for tertiary care. The average age was 25±7 years (range, 18–57 years). Males accounted for 96% of combat ocular trauma injuries. The vast majority of injuries were the result of blast and fragmentation (Table 3).[27] Despite aggressive eye protection recommendations, 179 (34%) of 523 eyes did not have protective eye armor at the time of injury. Most patients who were wearing eye protection at the time of injury wore U.S. Army-issued polycarbonate eyewear (Table 4).[28,29]

The median follow-up was 174±296 days (range, 3–1493 days). The percentage of eyes with 30 days of documented follow-up was 349 (75%) of 465 eyes, 6-month follow-up was accomplished in 253 (54%) of 465 eyes, 12-month follow-up was accomplished in 138 (30%) of 465 eyes, and 24-month follow-up was accomplished in 50 (11%) of 465 eyes. Three (0.08%) of 387 U.S. soldiers died during the follow-up period. This study included 58 (11%) of 523 eyes with undocumented visual acuity.

Regarding laterality of the 387 injured soldiers, 272 right orbit, or both, and 249 left globes or orbits, or both, were injured. Comparison of visual outcomes of right-sided versus left-sided COT revealed no statistically significant difference when evaluating for poor visual outcome (OTS grades 1, 2, 3; OR, 0.81; 95% CI, 0.55–1.20; $P = 0.32$).

All soldiers in this case series were U.S. military soldiers who underwent vision screening on entry into the military and before deployment. Only 1 soldier had a history of amblyopia in the injured eye. There was no known history of preexisting retinal or macular disease in this study group. Preinjury BCVA was 20/20 or better in all but 1 eye. Visual acuity was divided into subgroups to include all injuries, globe injury, oculoplastic injury, and neuro-ophthalmologic injury.

Closed-globe injuries accounted for 234 cases, and open-globe injuries accounted for 198 cases. Adnexal injuries occurred in 324 cases, and neuro-ophthalmologic cases totaled 135 (Fig 1).

Table 3. Combat Ocular Trauma

Age (yrs)	Median, 25±7 (range, 18–57)
Gender	96% male/4% female
Mechanism of injury	
Blast with fragmentary munitions	413/523 (79%)
Gun shot wounds	45/523 (9%)
Motor vehicle accidents	35/523 (8%)
Other injury	20/523 (4%)
Documented follow-up (days)	174±296 days (range, 3–1493)
Injury patterns	
Globe injury only	148/523 (28%)
Oculoplastic injury only	90/523 (17%)
Neuro-ophthalmologic injury only	23/523 (4%)
Combined globe with oculoplastic and/or neuro-ophthalmologic injury	416/523 (80%)
Combined oculoplastic with globe and/or neuro-ophthalmologic injury	323/523 (62%)
Combined neuro-ophthalmologic with globe and/or oculoplastic injury	115/523 (22%)
Unilateral	242/387 (63%)
Bilateral	145/387 (37%)
Globe/globe injury	186/523 (36%)
Globe/oculoplastic injury	54/523 (10%)
Globe/neuro-ophthalmic injury	2/523 (0.003%)
Oculoplastic/oculoplastic injury	28/523 (5%)
Neuro-ophthalmologic/ neuro-ophthalmologic injury	10/523 (2%)
Neuro-ophthalmologic/oculoplastic injury	0/523 (0%)

Globe Injury

Open-globe zone 1 injuries (n = 51) included corneal lacerations with or without stellate wounds. Seven of these cases required corneal glue and sutures to close the laceration. The mean corneal laceration length was 3.74 mm (range, 0.5–12 mm). Open-globe zone 2 injuries (n = 33) included corneoscleral lacerations extending up to 5 mm posterior to the limbus, with an average wound length of 8.71 mm (range, 0.5–32 mm). Open-globe zone 3 injuries with scleral lacerations totaled 110 cases. The average scleral laceration wound length was 6.21 mm (range, 0.5–20 mm).

Intraocular foreign body (IOFB) open-globe injuries (n = 86) occurred in zone 1 (n = 34), zone 2 (n = 16), and zone 3 (n = 36). The total number of IOFBs was 129. Seventeen cases had more than one IOFB per eye, and 7 cases had bilateral IOFBs. The mean IOFB size was 4.78 mm in longest dimension, and the mean volume was 32.03 mm^3. The composition included magnetic metallic (41%), nonmagnetic metallic (2%), nonorganic stone or cement (16%), glass (11%), organic autologous (5%), and unknown (26%). The depth of IOFB penetration was anterior chamber (4%), lens (0%), vitreous cavity (36%), retina (20%), subretinal space (5%), choroid (3%), sclera (4%), and perforation (28%).[30–32]

Globe perforations (n = 61) included all primary enucleations (n = 31) and eviscerations (n = 5). The primary enucleations and eviscerations usually occurred secondary to blast injury with fragmentary munitions. There is no defined category for complete destruction of the globe in the BETT classification system.[21] Perforations exited through zone 2 in 7 (11%) of 61 eyes and through zone 3 in 54 (89%) of 61 eyes. A perforating IOFB with BCVA of light perception or better was seen in 25 of 523 eyes.[33] Penetrating injury without IOFB (n = 32) occurred in zone 1 (11 [34%] of 32 eyes), zone 2 (10 [32%] of 32 eyes), and zone 3 (11 [34%] of 32 eyes). Rupture occurred in 19 (3.6%) of 523 eyes without a lacerating injury. Posterior rupture accounted for 17 of the 19 cases.

Traumatic macular holes totaled 17, with 11 occurring from closed-globe injuries and 6 from open-globe injuries (Colyer M, Weichel E. Traumatic macular holes secondary to combat ocular trauma. Paper presented at: American Society of Retina Specialists Annual Meeting, December 2007, Palm Springs, California). Traumatic macular holes accounted for 11% of all closed-globe zone 3 injuries.[34] Table 5 provides frequencies of additional globe injuries.

Oculoplastic Injury

Our rates of oculoplastic injury are higher than those of other studies describing combat ocular trauma.[35–39] Adnexal injuries included 181 lid lacerations (right upper lid, n = 63 [12%]; right lower lid, n = 36 [7%]; left upper lid, n = 54 [10%]; left lower lid, n = 51 [9%]). Lid laceration was a significant risk factor for poor visual outcome (OR, 3.6; 95% CI, 3.8–5.6; $P<0.0005$).[40] Secondary lid reconstructive procedures were required in 26 cases. Postinjury ptosis secondary to traumatic levator dehiscence occurred in 9 soldiers, 5 of whom underwent ptosis correction. Canalicular lacerations occurred in 12 cases with 4 Mini Monoka and 5 Crawford tube (FCI Ophthalmics, Marshfield, MA) surgical repairs. Documentation regarding the other 3 cases was not found.

Orbital fractures occurred in 181 (35%) of 387 of soldiers. The total number of walls fractured was 306, with an average of 1.69 walls per orbit (1 wall fracture, n = 78; 2 wall fractures, n = 60; 3 wall fractures, n = 20; 4 wall fractures, n = 12). The distribution of wall fractures was: roof, 45 (8%); floor, 129 (25%); medial wall, 83 (16%); and lateral wall, 55 (11%). Twenty-five (5%) of these fractures were repaired secondarily. Posttraumatic enophthalmos was documented in 13 (3%) of 523 eyes. An intraorbital foreign body was present in 102 (19%) of 523 orbits.[41,42] An emergent canthotomy or cantholysis was performed in the theater of combat operations in 24 cases, with 21 diagnosed cases of retrobulbar hemorrhage. In those eyes with an orbital wall fracture, the OR of BCVA worse than 20/200 was less than 1.0 (OR, 0.47; 95% CI, 0.32–0.70; $P<0.005$). This suggests a more favorable outcome in this subset of injuries, although the mechanism of any protective effect is merely speculative and cannot be concluded from the present data.

Enucleation was performed in 61 (12%) of 523 eyes. Primary enucleation (n = 31) and primary evisceration (n = 5) were performed in Iraq or Afghanistan secondary to perforating injuries, usually secondary to fragmentary blast munitions. Secondary enucleations after primary globe repair with postoperative NLP visual acuity accounted for 25 (5%) of 523 cases. Secondary enucleation secondary to proliferative vitreoretinopathy and phthisis occurred in 1 case. Four of the 5 primary eviscerations were performed by a single surgeon and were without signs of endophthalmitis. The mean time to enucleation was less than 24 hours for primary enucleations or eviscerations and 10 days for secondary enucleation after primary globe repair with NLP visual acuity. The

Table 4. Eye Protection

Documented eye protection	127/523 (24%)
Documented without eye protection	179/523 (34%)
Unknown use of eye protection	215/523 (41%)
Type of eye protection	
Non-U.S. Army-issued polycarbonate sunglasses	47/127 (37%)
U.S. Army-issued spectacle glasses	43/127 (34%)
U.S. Army-issued ballistic goggles	28/127 (22%)
Non-U.S. Army-issued glasses	9/127 (7%)

Table 5. Globe Injuries

Closed globe	n = 234
Zone 1	82
Zone 2	21
Zone 3	131
Open globe	n = 198
Zone 1	51
Zone 2	34
Zone 3	131
Frequency of Injury	n = 432
Conjunctival injury	59
Corneal abrasions	24
Corneal foreign body	66
Iritis	13
Hyphema	95
Iris injury	110
Sphincter tear	13
Iridodialysis	52
Angle injury	60
Angle recession	9
Cyclodialysis cleft	3
Zonular dehiscence	38
Lens subluxation/dislocation	29
Traumatic cataract	123
Vitreous hemorrhage	205
Grade 1	38
Grade 2	18
Grade 3	4
Grade 4	117
Traumatic retinal tear	138
Traumatic retinal detachment	101
Macula-on retinal detachment	24
Macula-off retinal detachment	70
Mean number of clock hours detached	9.4
Retinal dialysis	11
Choroidal hemorrhage	89
Choroidal hemorrhage involving the macula	57 of 89
Commotio retinae	64
Commotio retinae involving the macula	47 of 64
Subretinal hemorrhage	97
Subretinal hemorrhage involving the macula	60 of 97
Intraretinal hemorrhage	91
Chorioretinal rupture (sclopetaria retinitis)	44
Chorioretinal rupture involving the macula	17 of 44
Choroidal rupture	16
Choroidal rupture involving the macula	10 of 16
Preoperative proliferative vitreoretinopathy	10
Traumatic macular hole	18
Retinal vascular injury	10
Ophthalmic artery occlusion	5
Central retinal artery occlusion	1
Branch retinal artery occlusion	1
Central retinal vein occlusion	2
Branch retinal vein occlusion	1

type of orbital implant included silicone (n = 44), Medpor (Porex Surgical Inc., Fairburn, GA) (n = 6), and dermis fat graft (n = 3). Orbital implant complications occurred in 2 cases, which included 1 exposed implant and 1 infected implant.

Neuro-ophthalmologic Injury

Neuro-ophthalmologic injuries were divided into injuries of the cranial nerves versus direct injury to the brain involving the visual pathways and occipital cortex. Injuries to the optic nerve usually occurred from direct injury from an orbital foreign body or indirect injury. A traumatic optic neuropathy occurred in 103 (20%) of 523 eyes.[32] Direct injury occurred in 55 (11%) of 523 eyes, including avulsion or transection of the optic nerve in 9 (2%) of 523 eyes. Indirect injury without evidence of an orbital foreign body occurred in the remainder of the 48 cases (9%).

Cranial nerve injury included oculomotor nerve palsy (n = 9), trochlear nerve palsy (n = 3), and abducens nerve palsy (n = 3). Postinjury chronic diplopia occurred in 14 (4%) of 387 soldiers, with 6 (2%) of 387 requiring strabismus surgery. Facial nerve injuries associated with clinically significant lagophthalmos occurred in 17 cases.[43]

Brain injury without globe or oculoplastic trauma associated with persistent objective visual field defects occurred in 10 (2%) of 523 eyes.[44,45] Horner syndrome secondary to injury to the upper chest or neck occurred in 4 (1%) of 523 eyes. The documented median follow-up of brain-injured patients at the tertiary referral center was 185±230 days (range, 3–1084 days).

Complications and Surgical Procedures

A total of 330 documented surgeries were performed before arrival at WRAMC. This included 180 exploration or primary globe repairs, 40 enucleations, 66 lid laceration repairs, and 24 emergent canthotomy or cantholysis procedures. On arrival to WRAMC, a B-scan ultrasound was needed to evaluate 121 (23%) of 523 eyes. A total of 232 secondary ophthalmic surgeries were performed at WRAMC (range, 0–5). There were no cases requiring immediate vitrectomy on arrival at WRAMC. The most common surgeries were vitreoretinal procedures. These included pars plana vitrectomy (n = 121), pars plana lensectomy (n = 74), and scleral buckle (n = 11). Globe explorations were performed in 12 cases, with 3 of these cases requiring primary globe closure. Temporary keratoprosthesis with penetrating keratoplasty was necessary in 8 patients undergoing pars plana vitrectomy. Anterior segment reconstructive surgeries included cataract extraction with posterior chamber intraocular lens (n = 40). Nine of these cases (19%) were combined with pars plana vitrectomy, 31 (66%) had a posterior chamber intraocular lens implantation delayed 3 to 6 months, and 7 remained surgically aphakic. Iris injury occurred in 110 cases, with iris reconstruction using McCannel sutures in 7 patients and iris prostheses secondary to traumatic aniridia in 2 patients.

Anterior segment complications included 1 case of epithelial downgrowth into the anterior chamber. Anterior chamber washout was needed in 3 cases secondary to hyphema with high intraocular pressure. The most common indication for penetrating keratoplasty was visually significant corneal scarring. Penetrating keratoplasty was performed in 20 cases, with graft failure occurring in 7 of these cases. Corneal scarring or decompensation without penetrating keratoplasty occurred in 64 (12%) of 523 cases. Penetrating keratoplasty was not performed if the visual potential was believed to be worse than 20/400 and the soldier had normal vision in 1 eye. The most common cofactors associated with corneal scarring and poor visual potential were traumatic optic neuropathy and macular scarring. Infectious keratitis was documented in 5 cases (4 bacterial, 1 fungal).

Intraocular pressure at initial presentation to WRAMC was documented as high (>21 mmHg) in 19 (3.6%) of 523 cases, normal (5–21 mmHg) in 414 (79%) of 523 cases, low (<5 mmHg with intact sclera) in 8 (1.5%) of 523 eyes, and low secondary to posterior rupture or perforation in 12 eyes. (2.2%) of 523 eyes, traumatic glaucoma developed, with 7 (1.3%) of 523 eyes requiring a Baerveldt glaucoma implant (Pharmacia/Upjohn, Kalamazoo, MI). Glaucoma in closed-globe injury occurred only in 5 (2%) of 234 cases, with 3 cases needing glaucoma surgery. Closed-globe rates of other anterior segment complications included iridodialysis in 12 of 234 eyes, sphincter tear in 7 of 234 eyes, and angle recession in 6 of 234 eyes.

Table 6. Ocular Trauma Score and Likelihood of Final Visual Acuity*

Raw Score Sum	Ocular Trauma Score Grade	Final Visual Acuity: *No Light Perception*	*Hand Movements/Light Perception*	*1/200–19/200*	*20/50–20/200*	*≥20/40*
0–44	1	92%	7%	1%	0%	0%
45–65	2	39%	20%	13%	19%	9%
66–80	3	0%	2%	13%	31%	54%
81–91	4	0%	0%	0%	16%	84%
92–100	5	0%	0%	0%	0%	100%

*Globe injuries with 180-day postinjury visual acuity (n = 253).

Posterior segment complications included proliferative vitreoretinopathy in 39 (7.5%) of 523 eyes.[46] Phthisis bulbi, defined in this study as a irrepairable total retinal detachment associated with hypotony and decreased globe size, occurred in 25 cases. The single surgery anatomic success rate of traumatic retinal detachment repair for both closed- and open-globe injury was 69%.[34] There were no cases of laser demarcated retinal detachment.

Of the 198 open-globe injuries, no eyes received a vitreous tap and injection of intravitreous antibiotics for suspected posttraumatic endophthalmitis. Only 4 eyes received intravitreous antibiotics while in Iraq because of an organic IOFB. None of the enucleated eyes showed clinical signs of endophthalmitis. Additionally, pathologic analysis performed at the Armed Forces Institute of Pathology yielded no histologic evidence of endophthalmitis. There were no cases of sympathetic ophthalmia in this case series. In 2 eyes, an endogenous fungal endophthalmitis developed, whereas in 5 eyes, a fungal chorioretinitis associated with fungemia developed. There were no cases of siderosis bulbi with 14 of 86 retained IOFB cases followed up with electroretinography. One patient elected not to remove the IOFB and was followed up with serial electroretinography.

Concomitant nonocular-associated injuries occurred in 329 (85%) of 387 of soldiers in this study, including TBI from penetrating or closed head injury (66%), facial injuries (58%), extremity injuries (44%), traumatic limb amputation (12%), abdominal injuries (8%), thoracic injuries (7%), pelvic injuries (4%), burns (5%), and neck injuries (2%). Nonocular injury was not associated with worse visual acuity compared with ocular injury alone (OR, 1.02; 95% CI, 0.58–1.80; $P = 0.53$).

The median OTS was 70±26 (range, 12–100). Initial and final visual acuities were analyzed statistically in each category in terms of the OTS (Table 6). Ocular trauma score category 1 (0–44 points) predicted hand movements or worse vision, whereas OTS category 5 (92–100 points) predicted a final BCVA better than 20/40 (Spearman correlation coefficient, $r = 0.84$; n = 253; $P<0.01$). These outcomes validate the OTS in predicting visual prognosis in combat ocular trauma (Table 6).[47]

The visual acuity results for all globe injuries (n = 432) is shown in Figure 2A, whereas globe injuries with documented visual acuity both at the time of injury and at the 6-month follow-up visit (n = 253) are presented in Figure 2B. The mean grade of initial vision decreased from 2.7±1.8 to 3.3±1.6 at 6 months, for a mean change of 0.6±1.1 ($P<0.0005$). There was also a significant positive association between the initial and final visual acuity grade ($r = 0.80$; n = 253; $P<0.0005$; Fig 2B). Compared with initial visual acuity, the visual acuity at the 6-month follow-up improved in 28%, remained unchanged in 69%, and decreased in 3% ($P<0.0005$, Wilcoxon signed-rank test; Table 7).[23] Subgroup analysis of open-globe injuries showed an increase of visual acuity grade from 3.4±0.1 to 4.1±0.1 at 6 months, with a mean change of 0.7±0.1 ($P<0.0005$; Fig 3A). Closed-globe injuries also improved from 1.8±0.1 to 2.3±0.1 at 6 months, a mean change of 0.4±0.1 ($P<0.005$; Fig 3B). Both open-globe injuries ($r = 0.75$; n = 146; $P<0.0005$) and closed-globe injuries ($r = 0.78$; n = 107; $P<0.0005$) also dem-

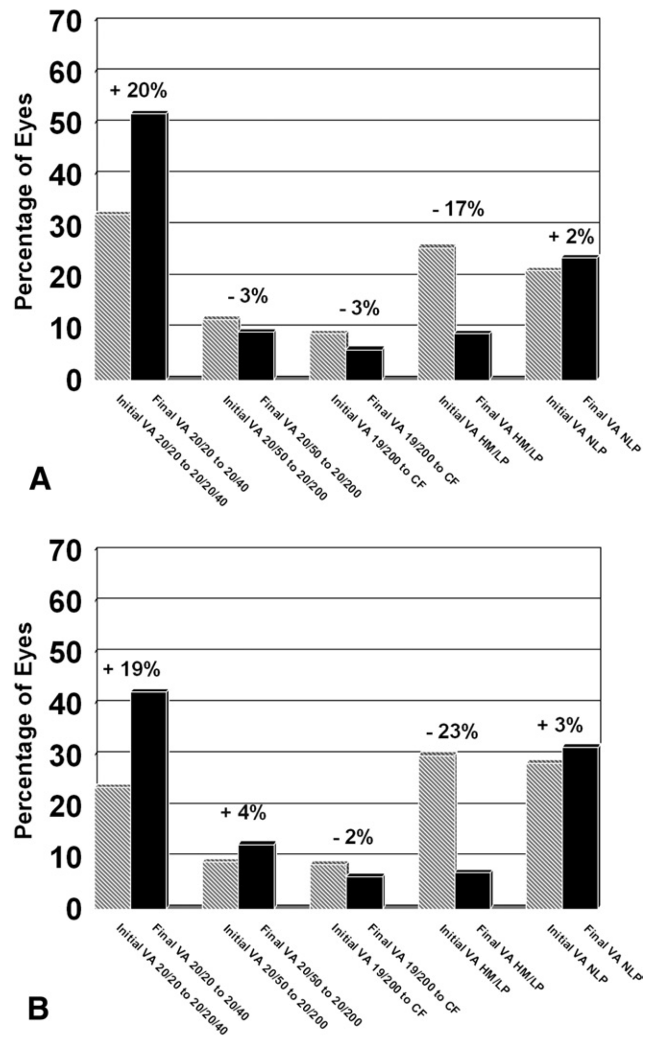

Figure 2. (**A**) Bar graph showing the visual outcomes comparing initial with last documented visual acuity of all globe injuries (n = 432 eyes). (**B**) Bar graph showing the visual outcomes comparing globe injuries with documented initial versus 6-month visual acuity (n = 253 eyes). CF = counting fingers; HM = hand movements; LP = light perception; NLP = no light perception; VA = visual acuity.

Table 7. Initial Visual Acuity versus 6-Month Visual Acuity (n = 253)

	6-Month Visual Acuity					
Initial Visual Acuity	*≥20/40*	*20/50–20/200*	*1/200–19/200*	*Hand Movements/Light Perception*	*No Light Perception*	**Total**
≥20/40	60	0	0	0	0	60 (23%)
20/50–20/200	15	8	0	0	0	23 (9%)
1/200–19/200	9	6	5	1	1	22 (9%)
Hand movements/light perception	23	18	11	14	10	76 (30%)
No light perception	0	0	0	3	69	72 (29%)
Total	107 (42%)	32 (13%)	16 (6%)	18 (7%)	80 (32%)	

onstrated a significant positive association between initial and 6-month visual acuity. The most frequent cause of poor visual outcomes (BCVA worse than 20/200) was traumatic optic neuropathy (n = 103), corneal scarring or decompensation (n = 64), enucleation (n = 61), or proliferative vitreoretinopathy (n = 39).

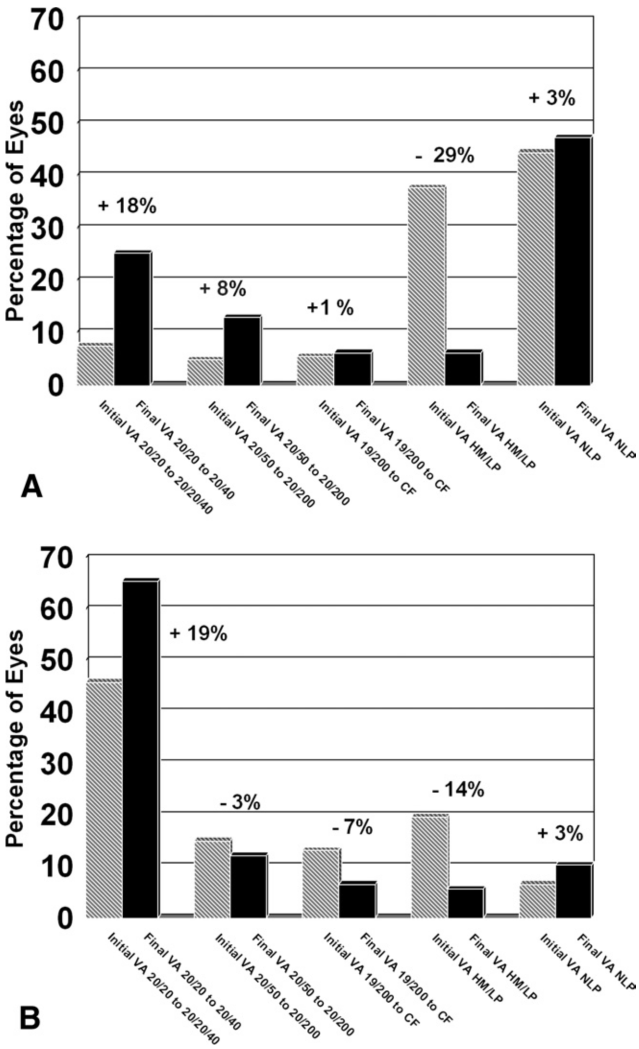

Figure 3. (**A**) Bar graph showing the visual outcomes comparing open-globe injuries with documented initial versus 6-month visual acuity (n = 146 eyes). (**B**) Bar graph showing the visual outcomes comparing closed-globe injuries with documented initial versus 6-month visual acuity (n = 107 eyes). CF = counting fingers; HM = hand movements; LP = light perception; NLP = no light perception; VA = visual acuity.

This study population underwent 562 surgical procedures to improve visual outcomes. Bilateral globe injuries occurred in 186 (36%) of 523 eyes, with 127 (33%) of 387 soldiers having final visual acuity of less than 20/200 in 1 eye (Table 3). Bilateral blindness, defined in this study as both eyes with final BCVA worse than 20/200, accounted for 13 (3.6%) of 387 soldiers. Bilateral NLP final vision occurred in 7 (1.8%) of 387 soldiers. Soldiers with BCVA worse than 20/200 in the better eye were transferred to one of the numerous Veterans Administration inpatient blind visual rehabilitation centers aimed at retraining blinded individuals in the performance of activities of daily living during a 12- to 16-week inpatient course.

Univariate and multiple logistic regression analyses were used to calculate which COT injury pattern caused the worst visual outcomes. Choroidal hemorrhage, globe perforation, retinal detachment, globe rupture, and afferent pupillary defect were found to give the highest ORs for poor visual outcome (Table 8). The results of multivariate regression analysis of COT showed that combined globe plus oculoplastic or neuro-ophthalmologic injury significantly increased the risk of having worse than 20/200 final BCVA (OR, 11.8; 95% CI, 4.0–34.7; $P<0.0005$; Table 9).

Discussion

Since the beginning of Operation Enduring Freedom in October 2001, no study has examined the visual outcomes of COT. Recent articles have focused on the incidence and type of injuries sustained in the Iraq theater of opera-

Table 8. Univariate Analysis of Ocular Injury with Best-Corrected Visual Acuity Worse than 20/200

Ocular Injury	Odds Ratio	95% Confidence Interval	*P* Value
Choroidal hemorrhage (macula)	111.5	15.2–819.0	<0.0005
Choroidal hemorrhage	54.1	19.1–153.2	<0.0005
Globe perforation	43.0	13.1–141.0	<0.0005
Retinal detachment	42.1	17.6–101.1	<0.0005
Globe rupture	27.8	3.7–211.1	<0.0005
Afferent pupillary defect	10.9	5.9–20.0	<0.0005
Subretinal hemorrhage (macula)	10.1	4.6–27.2	<0.0005
Proliferative vitreoretinopathy	8.9	3.5–23.7	<0.0005
Retinal tear	8.7	5.2–14.5	<0.0005
Scleral laceration	8.7	4.5–17.2	<0.0005
Corneoscleral laceration	4.0	2.0–7.9	<0.0005
Vitreous hemorrhage	4.0	2.6–6.3	<0.0005
Macular hole	3.5	1.0–11.5	0.03
Intraocular foreign body	1.2	0.7–2.1	0.49
Corneal laceration	0.5	0.2–0.9	<0.0005

Table 9. Multiple Logistic Regression Analysis of Combat Ocular Trauma Injury Patterns

Type of Injury	Odds Ratio	95% Confidence Interval	*P* Value
Globe + (oculoplastic or neuro-ophthalmic)	11.8	4.0–34.7	<0.0005
Neuro-ophthalmic + (globe or oculoplastic)	5.0	3.0–8.5	<0.0005
Oculoplastic + (globe or neuro-ophthalmic)	2.8	1.7–4.8	<0.0005
Globe injury only	1.3	0.4–4.5	0.58
Oculoplastic injury only	0.65	0.2–1.8	0.41
Neuro-ophthalmic injury only	0.8	0.1–12.4	0.88

Best-corrected visual acuity of 20/200 or better versus best-corrected visual acuity worse than 20/200.

tions.[31,33,48,49] Walter Reed Army Medical Center is the largest tertiary referral center for COT in the United States. This study presents the different categories of combat ocular trauma in U.S. soldiers treated at a single tertiary referral center, with longer-term outcomes than previously reported. Such a retrospective review has potential drawbacks, including incomplete records, lack of follow-up, and inability to contact patients (no consent, Health Insurance Portability and Accountability Act compliance, etc.). This contributes to a larger problem of poor longitudinal patient data tracking from the point of injury to the final outcome. Moreover, the inability to document consistently initial visual acuity early in the course after injury makes analysis and interpretation of the visual acuity outcomes and OTS difficult. Furthermore, long-term data tracking of these soldiers after they leave WRAMC is limited by a host of factors. Information management systems have made medical information more accessible, although combat injury information frequently is stored and controlled under the authority of different organizations.[50] Until a comprehensive health data system and a robust clinical data repository are readily available, field-tested, and fully deployed, descriptive studies such as the one reported herein provide the best source of large cumulative data. The results of this study contribute to the understanding of severity and management of COT in today's modern conflicts. However, large prospective, randomized trials controlling for type I and type II errors are needed to draw definitive scientific conclusions.

Combat ocular trauma differs from noncombat civilian ocular trauma.[51,52] First, the demographics differ between the 2 groups. During OIF, females accounted for 2% of the military wounded in action.[53] In noncombat ocular trauma, the male-to-female ratio is 4:1, compared with the COT male-to-female ratio of 24:1. In COT, blast or explosion injuries account for 79% of the injuries, as compared with 3% in noncombat civilian ocular trauma (Table 3).[54] Kuhn et al[55] reported 27% of eyes (3056 of 11 320) with BCVA worse than 20/200 in the United States Eye Injury Registry. This study revealed 33% of eyes (173 of 523) with BCVA worse than 20/200 secondary to COT. With a very high percentage of blast or explosive injuries, this study reported 63 (12%) eyes enucleated, 86 (16%) with a retained IOFB, 324 (62%) with a periocular injury, and 105 (20%) with traumatic optic neuropathy. The combination of globe-oculoplastic and neuro-ophthalmologic injury led to the worst visual prognoses.

Noncombat ocular trauma is associated with low rates of associated injuries, whereas 85% of COT soldiers have severe concomitant injuries and many are unconscious, intubated, or both, for long periods. Initial visual acuity could take days or weeks to obtain (average, 5 days). Ocular trauma within the United States usually occurs within driving distance or within the same time zone of a tertiary referral center. Most civilian ocular trauma patients are conscious and are able to describe the mechanism of injury. Combat ocular trauma injuries often occur long distances and many time zones away from tertiary care. The soldiers frequently are unable to be positioned after surgery from vitreoretinal surgery secondary to other associated injuries. The high rates of blast injuries are associated with TBI (66%). The authors have found that COT soldiers with TBI have decreased memory skills that can impact compliance during the perioperative and postoperative period.[56–58]

During World War II, only 20% of eye injuries achieved a visual acuity of 20/40 or better, compared with 52% in this study.[41] According to Hornblass[10,38] and La Piana and Hornblass,[37] 50% of penetrating ocular trauma led to enucleation in the Vietnam War, whereas 61 (31%) of 198 open-globe injuries led to enucleation in OIF/OEF. In the Vietnam War, only 25% of soldiers with eye injuries returned to active duty.[59] In this series of patients at WRAMC, 66% of the COT soldiers returned to active duty. The remaining 34% were referred for a medical evaluation board because they did not meet retention standards for fitness for duty in accordance with U.S. Army regulations.[60] Every soldier in this study was assigned to the WRAMC medical brigade and was not involved in work duties during recovery from their injuries. The cumulative number of work days lost because of ocular and concomitant injuries in this study group equaled 125 799 days. There is no method to determine how many of these days were caused by eye injury alone.

Many previous studies have looked at risks factors for poor visual outcome after trauma. These factors include the presence of an afferent pupillary defect, vitreous hemorrhage, or poor initial visual acuity.[40,61–65] This study supports the previous findings. However, the severity of COT has elucidated other findings that lead to poor visual outcomes. This study demonstrates that choroidal hemorrhage, globe perforation, retinal detachment, globe rupture, and afferent pupillary defect were the top 5 clinical findings associated with poor visual outcome (Table 8).

Within this study group of 387 soldiers, WRAMC has not seen a single case of posttraumatic endophthalmitis, sympathetic ophthalmia, or siderosis bulbi. All patients with open-globe injuries in OIF/OEF are started on topical and systemic fluoroquinolone endophthalmitis prophylaxis. The lack of these findings suggests that such measures have contributed to better visual outcomes.[31,66]

This study found the BETT useful for categorizing COT. However, complete destruction of the globe was difficult to categorize in the BETT classification system. The primary

enucleated globe in this scenario could be either a perforating or rupture injury and accounted for a large number of COT cases.

Family members of injured soldiers universally want a prognosis for their son's or daughter's ocular injury on arrival from overseas. The authors wanted to determine if the OTS was useful in predicting outcomes to better counsel the injured military service members. Using the OTS in the tertiary care setting has many flaws. The OTS was used retrospectively to correlate visual outcomes. The initial visual acuity may have been days or weeks after the initial injury and very frequently occurred after primary globe closure. Variables to include reverse afferent pupillary defect and late retinal detachment contributed to imperfect data collection. In the setting of COT, the OTS did suggest a correlation with final visual outcome and currently is used to compliment other published studies to predict the visual outcome of those injured during combat operations. However, a prospective trial is needed to validate these results.

Another shortcoming of the present study is the incomplete data on the use of eye protection among the injured soldiers. Data collection was imperfect, with 215 (41%) of 523 eyes with unknown use of eye protection. However, witnesses of the injury usually did not accompany the injured soldier on the medical evacuation helicopter to confirm the use of eye protection. Also, soldiers with posttraumatic amnesia secondary to TBI could not remember the events preceding their injury. Many of these injuries were devastating, with poor outcomes despite fairly rapid primary repair and evacuation for additional care. The authors believe that a fair number of these injuries would have been prevented by the appropriate use of protective eyewear and that some injuries in those who were wearing appropriate eye protection were less severe as a result of this use.[67] However, because of the nature of this study and the significant gaps in information available to the authors regarding eye protection, these hypotheses cannot be proved or disproved. Even so, common sense dictates that the primary emphasis among military eye care providers has been and should continue to be on prevention. Military ophthalmologists have stressed to soldiers, commanders, and senior leadership that the use of eye armor, like body armor, be mandatory for all combat soldiers. Wrap-around, polycarbonate lenses designed to block the force of a 0.22-caliber bullet from 20 feet have been developed by and for the Armed Forces. A variety of industry-produced alternatives (that have passed stringent military safety standards) are now a standard supply item thanks to the pioneering vision and hard work of Colonel Francis La Piana MD, FACS (Ret) and others.[28,68]

Future Directions

Many injured soldiers sustain complex, multisystem trauma including COT, amputations, TBI, and other complications. As a result, many are discharged to a rehabilitation center for long-term follow-up care and rehabilitation. The frequency and unique nature of these polytrauma blast injuries create the need for an interdisciplinary program to handle the medical, psychological, rehabilitation, and prosthetic needs of these individuals.

In December 2007, with the support from the American Academy of Ophthalmology, American Optometric Association, Blinded Veterans Association, and the National Alliance for Eye and Vision Research, Prevent Blindness America, the President of the United States signed into law the Military Eye Trauma Treatment Act of 2007.[69,70] This law requires shared ocular trauma information between ophthalmology and optometry in all branches of the Department of Defense and the Veterans Administration and mandates the creation of a center of excellence in prevention, diagnosis, mitigation, treatment, and rehabilitation of military eye injuries. The legislation also mandates the implementation of an ocular trauma registry to track soldiers from the time of injury through the Department of Defense medical care system and during their care in the Veterans Administration medical system. The Department of Defense and the Department of Veterans Affairs are in the process of developing and initiating this registry.

The findings in this study have enabled the authors to answer many of the questions related to visual prognosis secondary to COT. These findings have been integrated into the answers to questions asked by both U.S. soldiers and their family members from the initial presentation in the surgical intensive care unit to the end of follow-up. However, challenges exist to improving visual outcomes. This study identifies and describes the most common causes of COT-related vision loss in OIF and OEF. It is the first step toward focused research efforts to improve the visual outcomes of any soldiers injured in the future.

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